

Shape discrimination in domestic goats using a touchscreen task

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Article

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Abstract

Examining visual perception in ungulates provides valuable insights into the evolution of mammalian vision and helps improve domestic animal practices. In this study, we used a computer-controlled touchscreen task to investigate the visual shape-discrimination abilities of domestic goats (*Capra hircus*). Four goats were trained to discriminate pairwise combinations of eight simple geometric shapes. At the group level, the goats performed significantly better than chance for all shape pairs except for the round shape versus S shape pair, and at the individual level, they tended to show difficulties in discriminating shapes that shared local features such as curved elements or sharp corners. These results suggest a reliance on local visual features rather than global contours when goats visually discriminate simple shapes. Furthermore, comparing these findings with existing data from horses, dolphins, and chimpanzees revealed a consistent relative order of perceptual dissimilarity between goats and horses, as well as a strong consensus structure across all four species. Overall, these findings demonstrate that domestic goats rely on local featural processing, supporting a shared, conserved visual perception framework across ungulates and diverse non-human taxa.

Introduction

Comparative psychology has seen considerable progress in many species that were understudied in previous decades. Studying the psychology of hooved animals could help us understand how evolution and domestication shaped these animals' minds; they constitute an important evolutionary group, and many hooved animals have been domesticated. From both scientific and practical perspectives, it is essential to examine animals' basic physiological and psychological properties, such as vision and visual acuity. Studying the vision of domestic goats (*Capra hircus*) could help us understand how vision evolved and how it was affected by the domestication process, and should aid domestic animal management and welfare.

There have been several studies on goat vision. For example, Blakeman and Friend (1986) examined whether goats could successfully discriminate X and O shapes, 3.4 cm × 3.4 cm in size, at different distances (starting from 0.1 m). They found that two goats could not discriminate X and O when the distance reached 1.5 m, and two others failed to discriminate at 2.0 m, while all individuals could discriminate these shapes well when the distances were smaller. Cognitive tests using a screen or a touchscreen at close distances revealed visual discrimination of complex shapes, such as symbols, among goats (Gao et al., 2025; Langbein et al., 2006, 2007, 2008). However, complex shape discrimination could not provide detailed features and cues of goats' visual abilities.

Studies using similar simple shapes have been conducted in multiple species, including humans, chimpanzees, dolphins, and horses (Schubert et al., 2022; Tomonaga et al., 2014, 2015). The use of simple shapes can reveal specific features that animals focus on during visual discrimination and allows cross-species comparison, promoting understanding of species differences and evolutionary changes in visual discrimination abilities.

In this study of goats, we used visual discrimination tests conducted on touchscreens. The advantages of using a touchscreen are that stimuli can be well controlled in terms of size, location, and lighting, which is crucial for visual tests; there is no need for human experimenters to code the choices made, thus avoiding human bias; and the controlled testing environment improves efficiency after habituation.

Accumulating evidence suggests that a reliance on local rather than global features during visual discrimination is not unique to ungulates, but represents a widespread phenomenon across non-human animals. For instance, visual and cognitive experiments in pigeons (*Columba livia*) demonstrate a pronounced bias toward local stimulus features (Clark & Colombo, 2022) and that they discriminate different shapes using the cue of topological features (Watanabe et al., 2019). In non-human primates such as chimpanzees (*Pan troglodytes*), visual processing exhibits a stronger dependence on local features compared to humans (Fagot & Tomonaga, 1999; Imura & Tomonaga, 2013). Therefore, evaluating shape discrimination mechanisms in goats allows us to examine whether their visual processing reflects this general non-human tendency toward local features, while providing critical empirical data from previously unexamined ungulate species to clarify how visual discrimination strategies have differentiated across broader phylogenetic groups.

This study used touchscreen discrimination tasks to test the ability of four domestic goats to discriminate simple shapes. The shapes included a round shape ("O"), an X shape ("X"), a 90-degree rotated D shape ("D"), a triangle, a square, an H shape ("H"), and a Z shape ("Z"). The results were compared with those obtained in horses in a previous study (Tomonaga et al., 2015) to elucidate differences in shape discrimination between ungulate species. Another previous study has tested the discrimination of several pairs of simple shapes in chimpanzees and dolphins (Tomonaga et al., 2014). We then used the results of the shared tested pairs to compare across goats, horses, chimpanzees, and dolphins to show shape differences in larger species ranges.

Results

The test results at the individual and group levels are shown in Table 1. The mean accuracies for each pair are shown in Fig. 1. At the group level, the participants' performance was significantly better than chance for all pairs except for the O–S pair. At the individual level, performance was not significantly better than chance for the following pairs: O–X (Nishiki), O–D (Yoshino and Nishiki), O–S (all individuals), D–S (Yoshino and Nishiki), triangle–square (Yoshino, Nishiki, and Ryu), triangle–X (Hikari and Nishiki), triangle–Z (all individuals), square–X (Hikari, Nishi, and Ryu), square–Z (Yoshino and Ryu), H–X (Yoshino and Ryu), and H–Z (Ryu). The results of multidimensional scaling (MDS) analysis are shown in Fig. 2. The stress value was 5.67, and the R^2 value was 0.93.

Table 1
Mean accuracy and binomial test results

Participant	Hikari		Yoshino		Nishiki		Ryu		All	
Pairs [†]	Mean accuracy (%)	<i>P</i> value, binomial test	Mean accuracy (%)	<i>P</i> value, binomial test	Mean accuracy (%)	<i>P</i> value, binomial test	Mean accuracy (%)	<i>P</i> value, binomial test	Mean accuracy (%)	<i>P</i> value, binomial test
O-X	90	< 0.001 ***	63	0.030 *	54	0.235	94	< 0.001 ***	75	< 0.001 ***
O-D	75	< 0.001 ***	58	0.097	54	0.235	75	< 0.001 ***	66	< 0.001 ***
O-S	46	0.667	56	0.156	56	0.156	56	0.156	54	0.174
O-Tr	90	< 0.001 ***	79	< 0.001 ***	67	0.007 **	79	< 0.001 ***	79	< 0.001 ***
O-Sq	85	< 0.001 ***	77	< 0.001 ***	81	< 0.001 ***	96	< 0.001 ***	85	< 0.001 ***
O-H	98	< 0.001 ***	85	< 0.001 ***	85	< 0.001 ***	96	< 0.001 ***	91	< 0.001 ***
O-Z	96	< 0.001 ***	94	< 0.001 ***	75	< 0.001 ***	92	< 0.001 ***	89	< 0.001 ***
D-X	90	< 0.001 ***	94	< 0.001 ***	83	< 0.001 ***	94	< 0.001 ***	90	< 0.001 ***
D-S	81	< 0.001 ***	56	0.156	42	0.156	75	< 0.001 ***	65	< 0.001 ***
D-Tr	71	0.001 **	65	0.0147 *	75	< 0.001 ***	96	< 0.001 ***	77	< 0.001 ***
D-Sq	94	< 0.001 ***	83	< 0.001 ***	88	< 0.001 ***	92	< 0.001 ***	85	< 0.001 ***
D-H	81	< 0.001 ***	96	< 0.001 ***	83	< 0.001 ***	94	< 0.001 ***	88	< 0.001 ***
D-Z	81	< 0.001 ***	92	< 0.001 ***	77	< 0.001 ***	88	< 0.001 ***	85	< 0.001 ***
S-X	85	< 0.001 ***	98	< 0.001 ***	79	< 0.001 ***	71	0.001 **	83	< 0.001 ***
S-Tr	92	< 0.001 ***	90	< 0.001 ***	71	0.001 **	77	< 0.001 ***	82	< 0.001 ***
S-Sq	88	< 0.001 ***	96	< 0.001 ***	67	0.007 **	83	< 0.001 ***	83	< 0.001 ***
S-H	88	< 0.001 ***	94	< 0.001 ***	73	< 0.001 ***	88	< 0.001 ***	85	< 0.001 ***
S-Z	98	< 0.001 ***	96	< 0.001 ***	69	0.003 **	96	< 0.001 ***	90	< 0.001 ***
Tr-X	60	0.056	63	0.030 *	48	0.443	81	< 0.001 ***	63	< 0.001 ***
Tr-Sq	67	0.007 **	58	0.097	56	0.156	50	0.443	58	0.0125 *
Tr-H	67	0.007 **	65	0.015 *	79	< 0.001 ***	67	0.007 **	69	< 0.001 ***
Tr-Z	52	0.333	54	0.235	60	0.056	56	0.156	56	0.048 *
Sq-X	54	0.235	67	0.007 **	48	0.443	54	0.235	56	0.048 *
†S+ followed by S-. For example, in OX, O is S+ and X is S-. Tr, triangle; Sq, square. * <i>p</i> < 0.05; ** <i>p</i> < 0.01; *** <i>p</i> < 0.001.										

Participant	Hikari		Yoshino		Nishiki		Ryu		All	
Sq-H	75	< 0.001 ***	81	< 0.001 ***			81	< 0.001 ***	79	< 0.001 ***
Sq-Z	81	< 0.001 ***	58	0.097			54	0.235	65	< 0.001 ***
H-X	88	< 0.001 ***	52	0.333			58	0.097	66	< 0.001 ***
H-Z	65	0.015 *					58	0.097	61	0.009 **
†S+ followed by S-. For example, in OX, O is S + and X is S-. Tr, triangle; Sq, square. * <i>p</i> < 0.05; ** <i>p</i> < 0.01; *** <i>p</i> < 0.001.										

Compared with data from horses, the Mantel test revealed a statistically significant positive correlation between the discrimination accuracy matrices of horses and goats ($r = 0.6171$, $p = 0.011$, 999 permutations). Procrustes analysis demonstrated a moderate topological concordance between the two-dimensional (2D) MDS configurations of horses and goats ($m^2 = 0.5757$, $r = 0.6514$, $p = 0.086$, 999 permutations).

Regarding the comparison across goats, horses, chimpanzees, and dolphins, the results of the Generalized Procrustes Analysis (GPA) across the four species are shown in Fig. 3. The GPA alignment revealed a strong overall consensus structure across the species, accounting for 74.30% of the total variance. Individual species residual variances relative to the consensus configuration were 4.09 for dolphins, 5.49 for horses, 7.30 for chimpanzees, and 8.82 for goats.

Regarding the pairwise comparisons among species, the Procrustes analysis demonstrated that the alignment between horses and dolphins reached statistical significance ($m^2 = 0.329$, $r = 0.819$, $p = 0.012$, 999 permutations), showing a shared geometric representation of shape similarities between these two species. The alignment between dolphins and chimpanzees showed a marginal trend toward significance ($m^2 = 0.467$, $r = 0.730$, $p = .059$, 999 permutations). In contrast, no statistically significant similarities were observed among the remaining pairs: goat-horse ($m^2 = 0.675$, $r = 0.570$, $p = 0.294$), goat-dolphin ($m^2 = 0.536$, $r = 0.681$, $p = 0.098$), goat-chimpanzee ($m^2 = 0.643$, $r = 0.598$, $p = 0.235$), and horse-chimpanzee ($m^2 = 0.532$, $r = 0.684$, $p = 0.116$).

Discussion

In this study, we used touchscreen tasks to test the visual shape-discrimination abilities of domestic goats. We also compared the results with existing data from horses. Simple geometric shapes were used to investigate how goats perceive basic visual features and to examine differences between ungulate species and beyond.

The goats' performance was better than chance on most pairs, suggesting their ability to discriminate simple geometric shapes. They tended to confuse shapes that shared common local features such as sharp corners or curved elements, a result supported by the finding at the group level that performance for the O-S pair was at the level of chance. Also, at the individual level, apart from the O-X pair (Nishiki), all pairs that did not have above-chance-level performance shared either curved elements (O-D, O-S, and D-S) or sharp corners (triangle-square, triangle-X, triangle-Z, square-X, square-Z, H-X, and H-Z). This tendency is also clear in Fig. 2. These results suggest that goats may adopt featural processing when visually discriminating simple shapes. The chance-level performance of Nishiki for the O-X pair does not seem to fit this conclusion, but this could be attributable to individual differences. Nishiki showed poorer accuracy in training sessions. She was the oldest goat (Table 2), so this might reflect age differences in visual discrimination and the ability to complete cognitive tasks. Due to the limited number of participants, this possibility could not be confirmed, although confirmation may be possible with a larger sample size. Nevertheless, despite these individual differences, the 2D MDS analysis indicated a very good fit to the data ($R^2 = 0.93$, stress = 5.67). This confirms that a 2D perceptual space accurately represents how goats differentiate geometric shapes.

Table 2
Goat characteristics

Name	Sex	Age (years) when the experiment started	Kinship
Hikari	Female	9	-
Yoshino	Female	8	Nishiki's daughter, Ryu's sibling
Nishiki	Female	11	Yoshino and Ryu's mother
Ryu	Male	8	Nishiki's son, Yoshino's sibling

The comparison between goats and horses provided valuable insight into the evolution of vision in ungulates. The Mantel test showed a statistically significant correlation between the discrimination matrices of the horses and goats ($r = 0.6171$, $p = .011$). In other words, the difficulty in discriminating the pairs of shapes was highly consistent between the two species; shapes that were difficult for horses were also difficult for goats. The Procrustes analysis showed moderate concordance between the two species' 2D MDS configurations ($r = 0.6514$, $p = 0.086$). Although the Procrustes result is indicative of a trend rather than statistical significance, the overall spatial patterns were still quite similar. Goats and horses belong to different orders of ungulates (artiodactyls and perissodactyls), and they show differences in visual acuity and eye structure. However, our findings show that their perceptions of basic shapes are very similar. This suggests that the basic mechanisms of visual shape discrimination are likely conserved across ungulate species.

Expanding our comparison to include dolphins and chimpanzees (Tomonaga et al., 2014) alongside horses (Tomonaga et al., 2015) provided a broader perspective on visual perception across diverse phylogenetic groups. The GPA alignment demonstrated a clear consensus structure (74.30% of total variance) across all four species, indicating that basic visual shape processing shares fundamental properties among mammals, regardless of their evolutionary background or ecological niches.

However, pairwise Procrustes comparisons revealed subtle species differences within this shared framework. A statistically significant geometric alignment was observed between horses and dolphins, and a marginal trend was found between dolphins and chimpanzees. In contrast, goats did not show significant alignment with any single species in the pairwise comparisons, despite their moderate correlation with horses in the two-species 2D MDS analysis. These differences may stem from variations in visual acuity, ecological demands, or individual testing variation. Overall, these results suggest that while the primary perceptual mechanisms for basic geometric shapes remain largely conserved across mammals, fine-scale shape representations vary across species. Also, the pairs tested in these species were slightly different. While the pairs tested in goats (this study) and horses (Tomonaga et al., 2015) were the same, the S shape was not tested in other species (Tomonaga et al., 2014) therefore was not included in the four-species comparison. The goats showed difficulties in discriminating S shape with O (all individuals) and also with D (Yoshino and Nishiki), so the shape S could potentially contribute a lot to the discrimination matrix, making goats' performance more different than other species if S shape is not included (goats had the individual species residual variances relative to the consensus configuration of 8.82, the biggest among all the four species).

The shared consensus structure identified in our four-species GPA comparison, alongside the local feature confusion observed in goats, provides further insight into the cognitive mechanisms underlying cross-species shape perception. Beyond ungulates, reliance on local features rather than global configurations during shape discrimination is a well-documented phenomenon in other non-human animals, including pigeons (Clark & Colombo, 2022; Watanabe et al., 2019) and non-human primates such as chimpanzees (Fagot & Tomonaga, 1999; Imura & Tomonaga, 2013). The finding that goats, horses, dolphins, and chimpanzees share a substantial overall perceptual consensus (74.30% of total variance) suggests that a local feature bias may be a fundamental processing strategy widely preserved across diverse non-human taxa. Even though species display fine-scale perceptual differences due to varying visual acuities and ecological constraints, the shared emphasis on local visual cues appears to form a common perceptual foundation across these widely divergent species.

The use of a touchscreen in this study conferred several benefits. First, it provided a controlled environment for cognitive testing, which is especially important when conducting visual tasks. Also, the controlled conditions provide a basis for validation in future studies. Furthermore, the testing environment and method were similar to those of a previous horse study (Tomonaga et al., 2015), allowing for more valid conclusions.

Our study had some limitations. The goats Yoshino and Nishiki did not finish the tests on all pairs, leading to missing data for some pairs. Yoshino became ill and could not continue the experiment. Nishiki's performance dropped in later conditions, possibly because the discrimination was too difficult or because she started to lose interest in getting rewards for more than 50% of trials. A long and simple

task may be problematic for some individuals in terms of maintaining high motivation. Finally, the number of participants was small; although this is common in touchscreen studies of large farm animals, it limits our understanding of individual variation. Testing more individuals and other ungulate species in the future will help clarify how visual abilities evolved in hoofed mammals.

In conclusion, domestic goats successfully learned to discriminate simple shapes on touchscreens, primarily relying on local features during visual tasks. Comparative analyses revealed that goats share a similar shape perceptual space with horses, and a broader consensus structure across goats, horses, dolphins, and chimpanzees. These findings suggest that a local featural processing strategy and basic shape perception mechanisms are widely conserved across diverse non-human taxa, providing new insights into the visual cognition and evolutionary psychology of hoofed animals and beyond.

Method

Participants

Four domestic goats (*Capra hircus*) at Kyoto City Zoo participated in this study (Table 2). They lived in a social group consisting of seven goats and one sheep and had access to an enriched outdoor compound of approximately 400 m². There were several indoor rooms measuring 3.9–7.9 m². A hallway for zoo staff and experimenters was located between the outdoor compound and the indoor rooms. The animals could use the outdoor compound during the day when it was not raining heavily, and the compound was open to visitors twice a day; the visitors were able to enter the outdoor compound and interact with the animals. The experiments were conducted at noon, when no visitors were allowed inside. Food and water were available to the animals at all times. The goats were trained to use the touchscreen for cognitive tests, such as symbol discrimination (Gao et al., 2025). This research was approved by the Ethical Committee of Kyoto City Zoo (#2024-KCZ-002, 2025-KCZ-006, 2026-KCZ-006) and followed the animal welfare guidelines of the Kyoto City Zoo.

Apparatus

A 23.8-inch touchscreen (P2424HT; Dell, Round Rock, TX, USA; 1,920 × 1,080 pixels) on a wheeled stand (TF-520B; Hayami, Tokyo, Japan) was used for the study. The center of the screen was approximately 105 cm from the ground, at the same height as the goats' heads when they stood near the screen. The programs for the experiment were written in Visual Studio 2022 (Microsoft Corp., Redmond, WA, USA) and run on a laptop (Dragonfly G4; HP, Palo Alto, CA, USA) connected to the touchscreen. The laptop and touchscreen were positioned in the hallway, while the goats stayed inside their outdoor compound. The fence between the hallway and the compound was low, with widely spaced bars, so the goats could easily position their upper bodies in the hallway area to participate in the experiments (Fig. 3). One experimenter usually remained within the goat compound to ensure that only one goat stood close to the experimental setup at a given time. The leading experimenter(s) remained in the hallway to conduct the experiment. The experimenter who provided the food reward usually stood behind the touchscreen stand and avoided eye contact with the goats during the experiment. Food rewards were provided to the goats on a plastic spoon via an opening in the stand immediately under the middle part of the touchscreen.

Stimuli and procedure

Each trial started with a beep sound, and two choice alternatives then appeared side by side on the screen. If the goat chose the correct one (S+) by touching it, a chime sounded, and the human experimenter gave the goat a piece of carrot as a food reward, approximately 1 cm × 1 cm × 1 cm in size. If the goat made an incorrect choice by touching the distractor (S-), a buzzer sounded, no food reward was provided, and there was a 3-s timeout. In later training phases, a 5-s timeout was sometimes implemented to facilitate learning. Each session consisted of 12 trials, with an inter-trial interval of 2 s.

The stimuli used in this experiment were the same as those used in a visual-discrimination study of horses (Tomonaga et al., 2015): a round shape ("O"), an X shape ("X"), a 90-degree rotated D shape ("D"), a triangle, a square, an H shape ("H"), and a Z shape ("Z"). Throughout the experiment, the X shape was always the S- stimulus. A pretraining phase allowed the goats to familiarize themselves with the testing paradigm. In the pretraining phase, O was the S+ stimulus, and X was the S- stimulus. O was 400 × 400 pixels in size, and X was 160 × 160 pixels. Once there were fewer than two errors per session, the goats progressed to the next stage, where O was still 400 × 400 pixels, whereas X was 240 × 240 pixels. Once high-level performance was achieved, the animals progressed to the training and testing stages, where all stimuli were 400 × 400 pixels.

The first S+ stimulus was the O shape. The animals completed at least eight sessions of O versus X to learn that the O was the target, until they reached the criterion (i.e., ≤ 2 errors/session for two consecutive sessions and total accuracy $\geq 80\%$ for four consecutive sessions). They then underwent tests in which O was the S+ stimulus, and D, S, triangle, square, H, or Z was the S- stimulus. Four sessions were completed for each pair, and the testing order was randomized.

D was the S+ stimulus in the trials that followed. The animals completed at least eight trials of D versus X until they satisfied the performance criterion mentioned above. They then completed trials in which the S+ stimulus was D, and the S- stimulus was S, triangle, square, H, or Z (four sessions per S- stimulus). There were no reversed tests such as D (S+) versus O (S-). The S+ stimulus was then changed to S, and the procedure was repeated until the last pair (i.e., H [S+] versus Z [S-]). At the beginning of each testing day, a warm-up session was completed as a reminder of the identity of the S+ stimulus. Two or three warm-up sessions were sometimes completed if performance was insufficient.

In the later stages, both Ryu and Yoshino had significant difficulties completing the H versus X trials, whereas Nishiki had difficulties with the triangle versus X trials. Therefore, the criterion for passing the training was changed to performance significantly better than chance for four consecutive sessions (i.e., more than 29 trials correct). Yoshino dropped out of the experiments in the middle of the training on the H versus X pair due to poor health. Nishiki discontinued the experiments after completing the tests in which the S+ stimulus was the triangle because she was not motivated. Hikari and Ryu completed the trials for all pairs.

Data analysis

For all the pairs not involving X, the data from the test sessions (four sessions for each pair) were analyzed. For pairs involving X, the data from the first four sessions were used to determine discrimination performance. We calculated accuracy for each individual and each pair, and binomial tests were conducted to compare performance against the level of chance. The same analysis was performed at the group level. Then, using R (R Core Team, 2026), we subjected the mean values for all individuals to an MDS analysis, mapping the distances between the stimuli on two dimensions to determine discrimination performance.

Using data from previous studies of horses (Tomonaga et al., 2015), we conducted a comparison to evaluate whether horses and goats share comparable perceptual topology for geometric shapes. For goats, the Z-X pair was not tested, and the missing value was imputed using the mean dissimilarity of all observed non-diagonal pairs prior to MDS fitting and comparison. We conducted interspecific comparisons using two complementary statistical approaches in R. First, we performed a Mantel test (based on Spearman's rank correlation) on the discrimination accuracy matrices of the two species to examine whether the order of perceptual dissimilarity was consistent between horses and goats, without relying on dimensionality reduction. Second, we applied Procrustes analysis using the *vegan* package (Oksanen et al., 2026) to quantify geometric alignment and topological concordance between the 2D MDS spatial configurations of the two species.

For the comparison across goats (data from this study), horses (Tomonaga et al., 2015), chimpanzees, and dolphins (Tomonaga et al., 2014), the shared shapes that were tested in all four species are as follows: round shape ("O"), X, rotated D ("D"), triangle, square, H, and Z. Therefore, data involving other shapes in goats and horses were not included for the species comparison. Generalized Procrustes Analysis (GPA) was performed using the *FactoMineR* package in R (Lê et al., 2008) to systematically compare the two-dimensional MDS perceptual spaces of these four species (goats, horses, dolphins, and chimpanzees). To test the statistical significance of pairwise structural similarities between species, permutation-based Procrustes analysis (protest in the *vegan* package, 999 iterations; Oksanen et al., 2026) was conducted for all six species pairs.

Use of large language models

Large language models were used to refine the language in this manuscript.

Declarations

Additional Information

The authors declare no competing interests.

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Author Contribution

J. G. and M.T. designed the study. J. G. and M. T. conducted the experiments. J. G. did the data analyses. The manuscript was written by J.G., and M.T. provided suggestions for the draft.

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Data Availability

All data are available in the manuscript or the supplementary materials.

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Figures

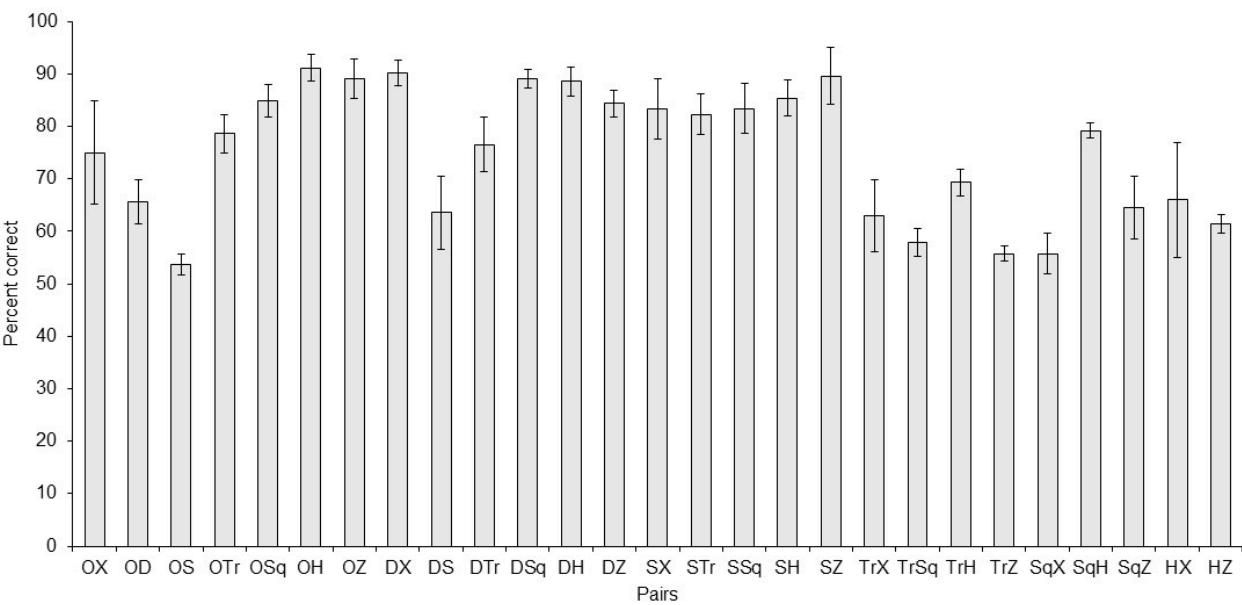


Figure 1

Mean percent correct for each stimulus pair for all participants. The names of all pairs start with “S+” and end with “S-”. For example, in O–D, O = S+, and D = S-. Tr, triangle; Sq, square. Error bars represent the standard error of the mean.

This figure shows the percent correct for all pairs. The names of each pair start with S+ and end with S-. For example, OD means O is S+ and D is S-. Tr: short for Triangle; Sq: short for Square. Error bar: SEM.

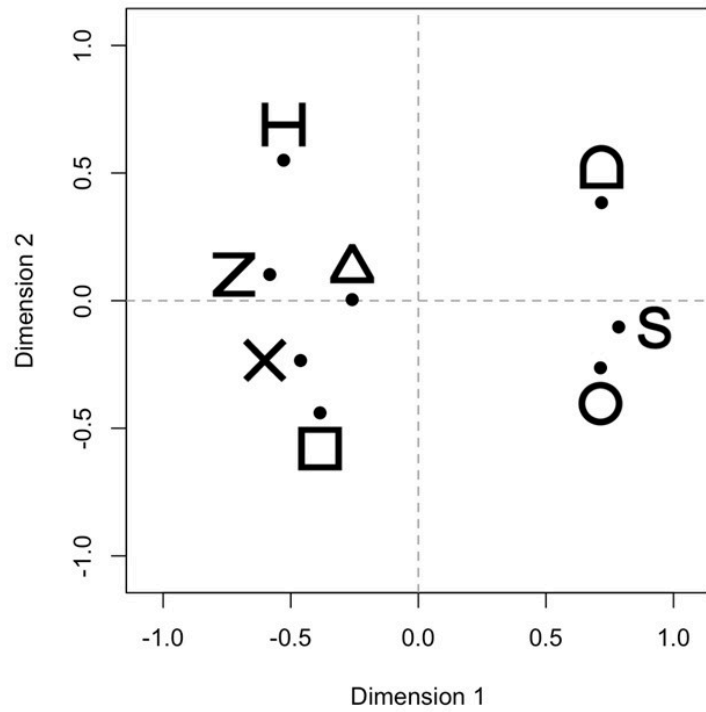


Figure 2

Results of multidimensional scaling analysis. The shapes beside each data point indicate the actual shape of interest. Stress value = 5.67, $R^2 = 0.93$.

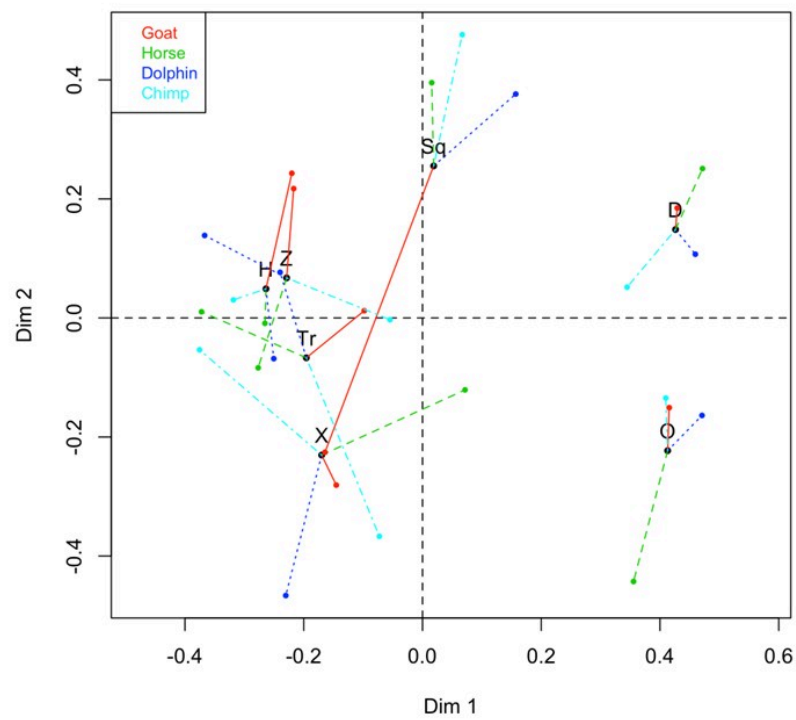


Figure 3

Generalized Procrustes Analysis (GPA) alignment of the two-dimensional MDS perceptual configurations for seven geometric shapes (O, X, D, triangle, square, H, Z) across goats, horses, dolphins, and chimpanzees. Individual shape positions for each species are connected to their corresponding consensus positions in the consensus space. Different colors represent individual species.



Figure 4

Experiment setup. Ryu performing the discrimination task between O and Z. He could easily move his head into the hallway to perform the touchscreen task. A food reward was delivered from an opening in the stand directly under the screen.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementarymaterial1DiscriminationdataGao.xlsx](#)
- [Supplementarymaterial2DiscriminationofDXbyRyuGao.mov](#)